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VENTING OF PRESSURE THROUGH PERFORATED PLATES

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Results are presented for a series of experiments designed to determine the pressure venting characteristics of perforated plates. Pressure decay from a chamber as a function of the vented area is presented for a series of perforated plates.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS

LIST OF TABLES

I. INTRODUCTION

This is one of a series of reports which define parameters affecting the transmission of shock waves and quasi-static gas flow through vented plates. References 1 and 2 describe the influence on shock wave attenuation by target test plates as a function of vent area, size, and number of holes.

Results are reported here for the rate of decay of chamber pressure as a function of venting. Various hole sizes were used in the attenuator plates to control the rate of flow from the containment chamber. The overpressure versus time recorded in the chamber documents the rate of gas venting as a function of vent area and chamber volume.

A. Background.

A basic requirement under one phase of the Army's program to modernize munition production facilities was to develop a base of general knowledge pertinent to the design of suppressive shields being considered for the containment of blast and fragments generated from accidental explosions.

When an internal explosion occurs the blast wave reflects and re-reflects and as unburned detonation products combine with available oxygen, a gas pressure rise occurs. This gas pressure is often referred to as the quasi-static pressure because it can last long enough to apply essentially a static internal gas pressure load to the structure. The rate of decay of the quasi-static pressure is a function of the structure volume and vent area. Therefore, an understanding of the venting process is needed to determine the internal loading of a structure, in order to better design structures to resist the effects of accidental explosions.

B. Objectives.

The objectives of the experiments conducted in this program were (1) to determine the effect of known vent areas on the decay rate of venting gas as it flows from a containment chamber, (2) to compare the results with other experimental and theoretical work, and (3) to determine the effective vent area of multiple plates from results obtained on single plates with known vent areas.

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1. *Charles Kingery and George Coulter, "Shock Wave Attenuation by Single Perforated Plates," Ballistic Research Laboratory Memorandum Report No. 2664, August 1976.* (AD #B013764L)
2. *C. Kingery, R. Pearson, and G. Coulter, "Shock Wave Attenuation by Perforated Plates With Various Hole Sizes," BRL Memo Report No. 2757, June 1977.* (AD #A041854)

II. EXPERIMENTAL PROCEDURE

The details of the vented plates and the experimental setup are presented in this section.

A. Instrumentation.

The instrumentation consisted of pressure transducers, oscilloscopes, and still cameras. The overpressure decay versus time was recorded using piezo-electric transducers, Susquehana Instruments Company Model ST-4, with Kestler Model 566 charge amplifiers. The output voltage from the transducers and charge amplifiers were fed into Tektronix Model 502-A oscilloscopes where the display was photographed, giving a permanent record. The voltage-time records were put into digital form, then engineering units were calculated and results plotted as shown in the Results Section.

B. Containment Chamber.

The driver section of the 10.2 cm shock tube was chosen as the containment chamber because of its simple operation and ease of instrumentation. A sketch of the portion of the tube used for this experiment is presented in Figure 1. Note that the target vent plate was placed next to the compression chamber and followed by the containment diaphragm.

C. Vented Targets.

Several, vent plates were manufactured so that both hole size and number of holes could be varied during the test series. Plate vent area (A_v) was varied from 1 to 50 percent of the completely unobstructed tube cross section (A_v = 100 percent).

Both single vent plates and multiple plates (with 1/4-inch spacers) were clamped at the mouth of the driver chamber as shown in Figure 1. Two test series were conducted where the chamber was pressurized with helium to approximately 827 kPa (120 psi) and 2413 kPa (350 psi) overpressure. The diaphragm was ruptured and the gas vented through the plates. The decay of pressure versus time within the chamber was recorded during this process.

Sketches of the vent plates are given in Figure 2 showing the hole sizes and locations. Combined plates were stacked so the flow did not have a direct line of sight path through the stack. The stacked plates were clamped at the same location as were the single plates. All stacked plates had 1/4-inch spacers between them as shown in Figure 1. All plates were 1/4-inch thick. One slotted plate was also tested.

A sketch of a nested I-beam, Target 11, as shown in Figure 2, was also exposed.

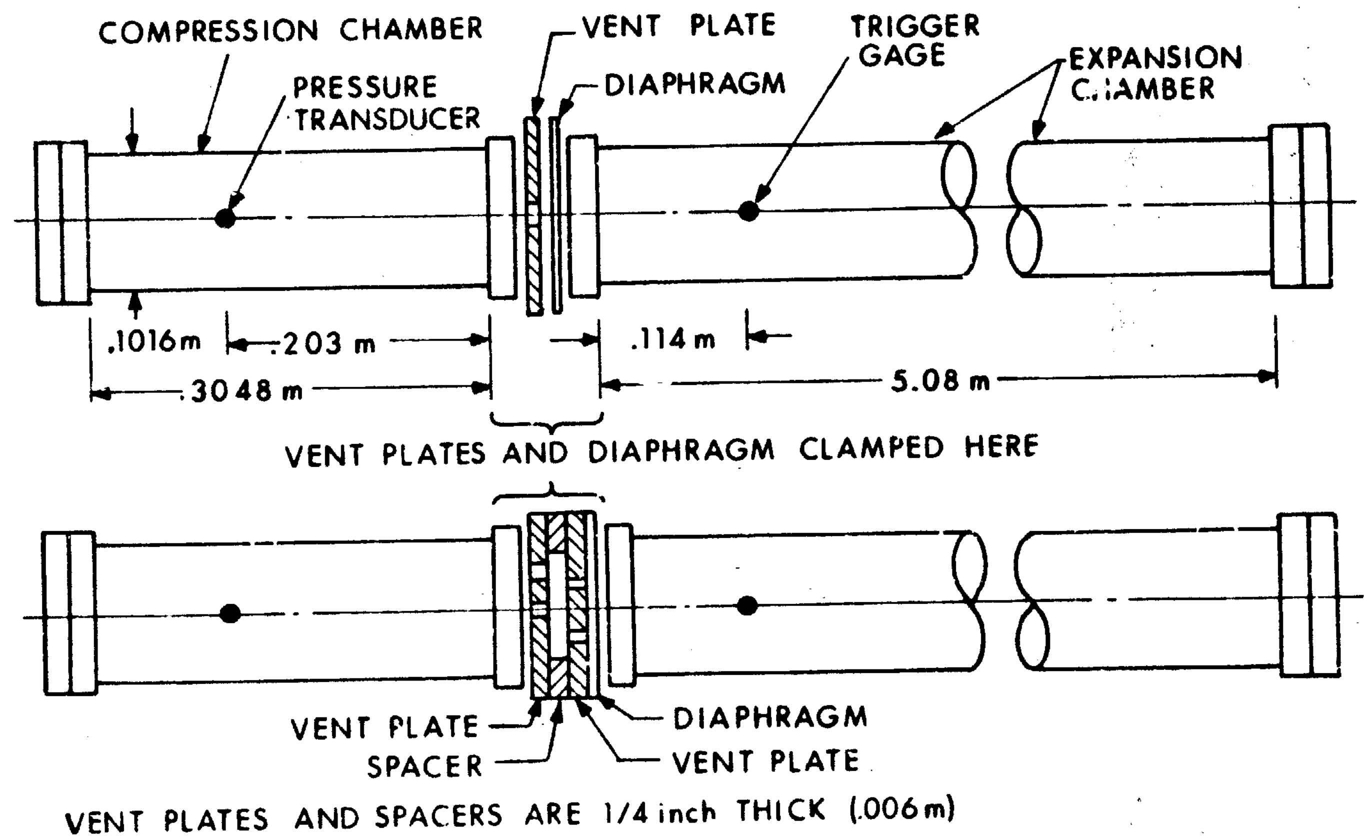

Figure 1. Experimental Test Setup for Single and Multiple Plates

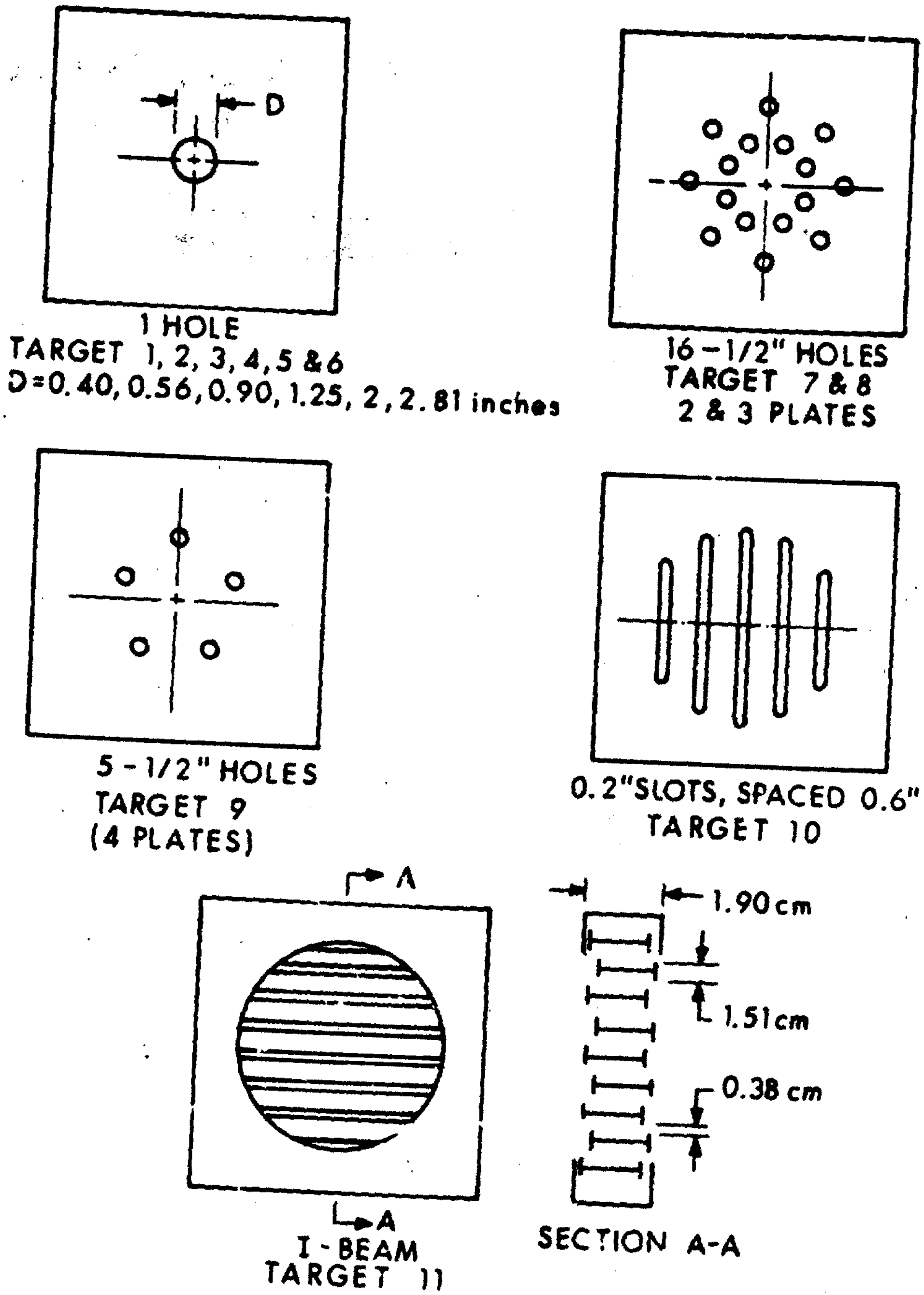

Figure 2. Sketches of Vent Plate Targets

III. RESULTS

A series of tests was run with various vent plates clamped at the exit opening of a gas filled chamber. Chamber overpressure levels of approximately 827 kPa (120 psi) and 2413 kPa (350 psi) of helium gas were used for the tests. The test matrix for the single plates with pertinent information is listed in Table I. The plates were designed with hole sizes in English units. For convenience and ease of presentation they are presented in the table as such, since the percentage of vented area to the total area of the shock tube cross-section would remain the same in any set of units. The ratios of the area vented (A_V) to the volume (V) of the chamber are presented in both English and SI units. Information on multiple plates and other configurations are listed in Table II.

TABLE I. Data on Single Plate Vent Targets.

Shot No.	Target No.	Hole Diameter in.	Percent Open	A_V/V ft^{-1}	A_V/V m^{-1}	Chamber Pressure kPa
244	1	0.40	1.00	.010	.0328	2413
255	2	0.56	1.96	.020	.0643	2413
239	3	0.90	5.06	.051	.1662	2399
241	4	1.25	9.77	.098	.3205	2427
246	5	2.00	25.00	.250	.8206	2413
276	6	2.81	49.35	.494	1.619	2406
		4.00	100	1.00	3.282	2413
262	3	0.90	5.06	.051	.1662	827
268	5	2.00	25.00	.250	.8206	820
270	6	2.81	49.35	.494	1.623	814

Ratio A_V/V = Area Vented/Volume of Chamber

Percent Open = Vent Area/Unobstructed Tube Area x 100

Chamber Volume = .00247 m^3 (.08727 ft^3)

100 percent Open = .00811 m^2 (.08727 ft^2)

Percent Open X 0.03282 m^{-1} = A_V/V m^{-1}.

TABLE II. Data on Multiple Plate Vent Targets

Shot No	Target No	Number of Holes and Size	Number of Plates	Each Plate Vent Area m	Each Plate Percent Opening
186	7	16 - 1/2 in.	2	.0020	25
260	8	16 - 1/2 in.	3	.0020	25
352	9	5 - 1/2 in.	4	.0006	7.8
257	10	0.2 in. slots, spaced 0.6 in.		.0021	26
252	11	model - nested I-beams		-	-

A. Single Plate Venting.

The decay of overpressure with time, in the compression chamber, for Target Plates 1 through 6 is presented in Figure 3 for a chamber pressure of 2413 kPa (350 psi). Note that as the vent area (A_v) increases the duration of the gas pressure decreases. The curves are identified by both the percentage of the tube cross section open and the ratio of vented area (A_v) to the volume (V) of the chamber. These decay curves will be used to establish the effective vent areas of other targets as well as determine equations to describe the phenomenon of gas flow and venting from pressurized chambers.

The decay of overpressure versus time for Target Plates 3, 5, and 6 is presented in Figure 4 for a starting chamber pressure of 827 kPa (120 psi).

The chamber pressure decays versus time presented in the curves from Figure 3 have been cross-plotted in Figure 5 as decay time versus vent area percent for constant chamber pressures. This figure can be used to determine the effective vent area of multiple plates, slotted plates, and nested I-beams subjected to the same initial chamber pressure. The percent of the target plate open multiplied by 0.03282 m^{-1}, equals A_v/V m^{-1}.

B. Multiple Plate Venting.

Data on targets tested other than single plates with holes, are presented in Table II. This section will discuss the effectiveness of multiple plates, establish effective vent areas, and check proposed methods of predicting effective vent areas. The chamber pressure decay

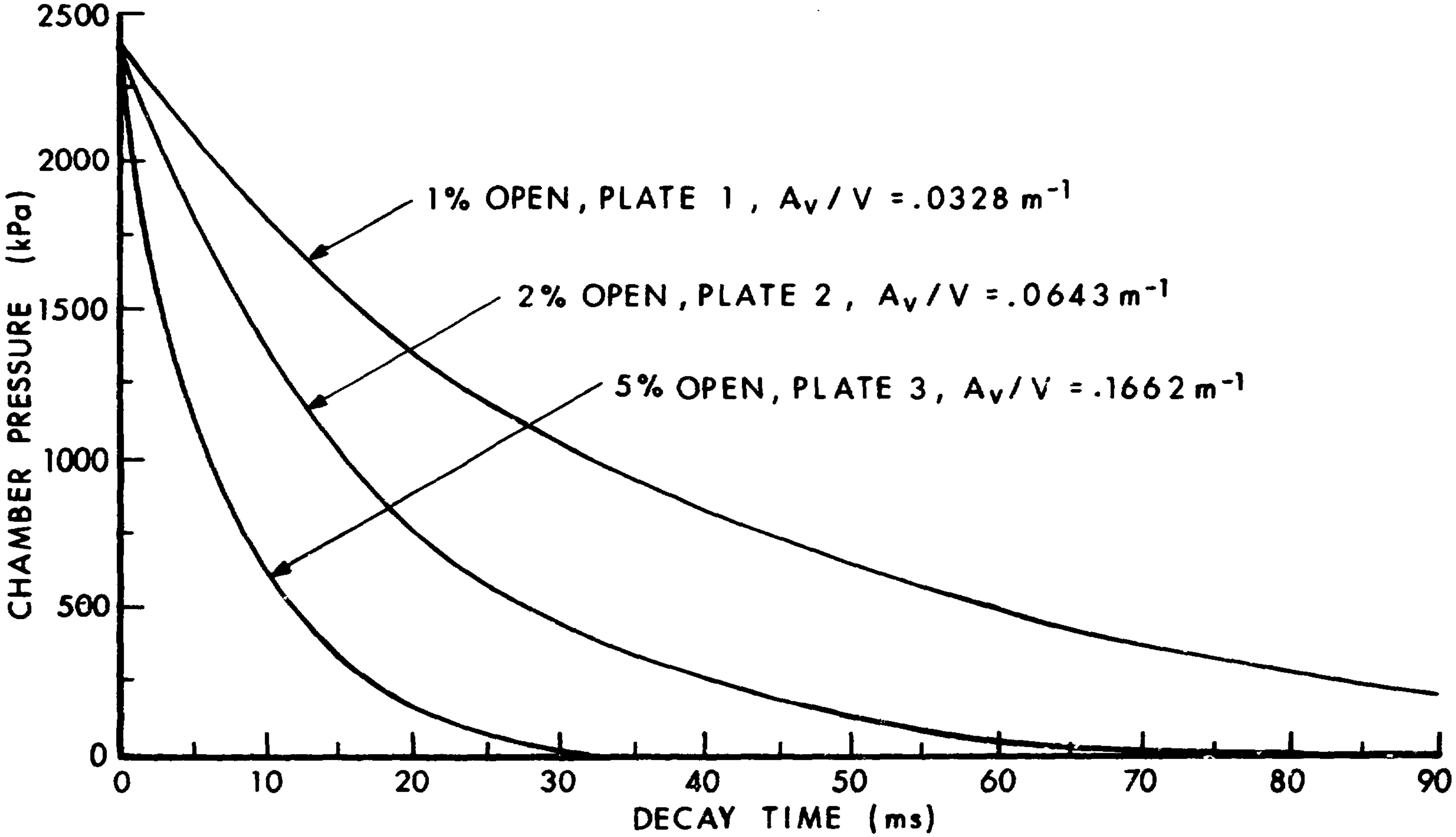

Figure 3. Chamber Pressure Decay versus Percent of Plate Vented - 2413 kPa Initial Chamber Pressure

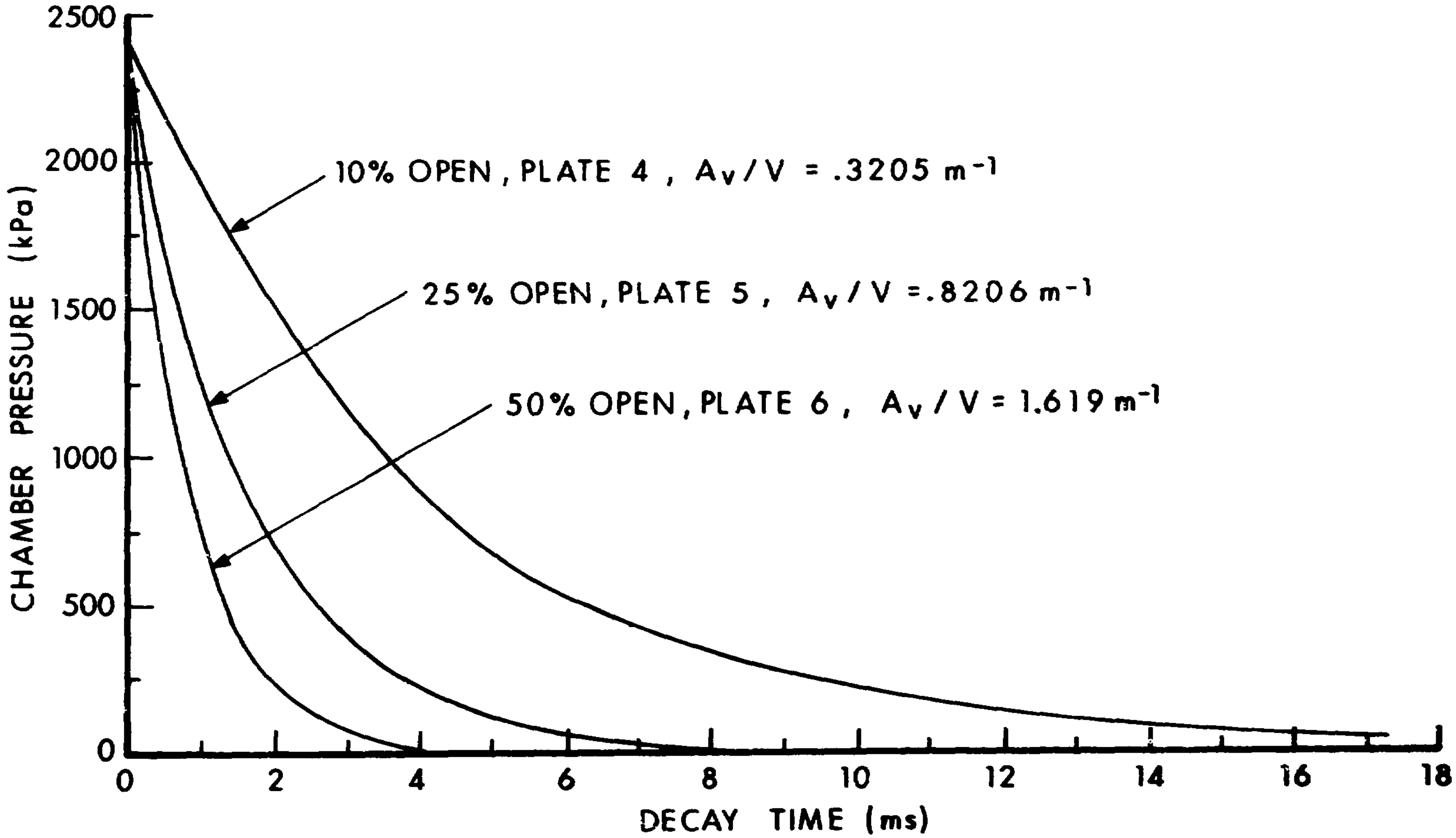

Figure 5. Chamber Pressure Decay versus Percent of Plate Vented - 2415 kPa Initial Chamber Pressure (Continued)

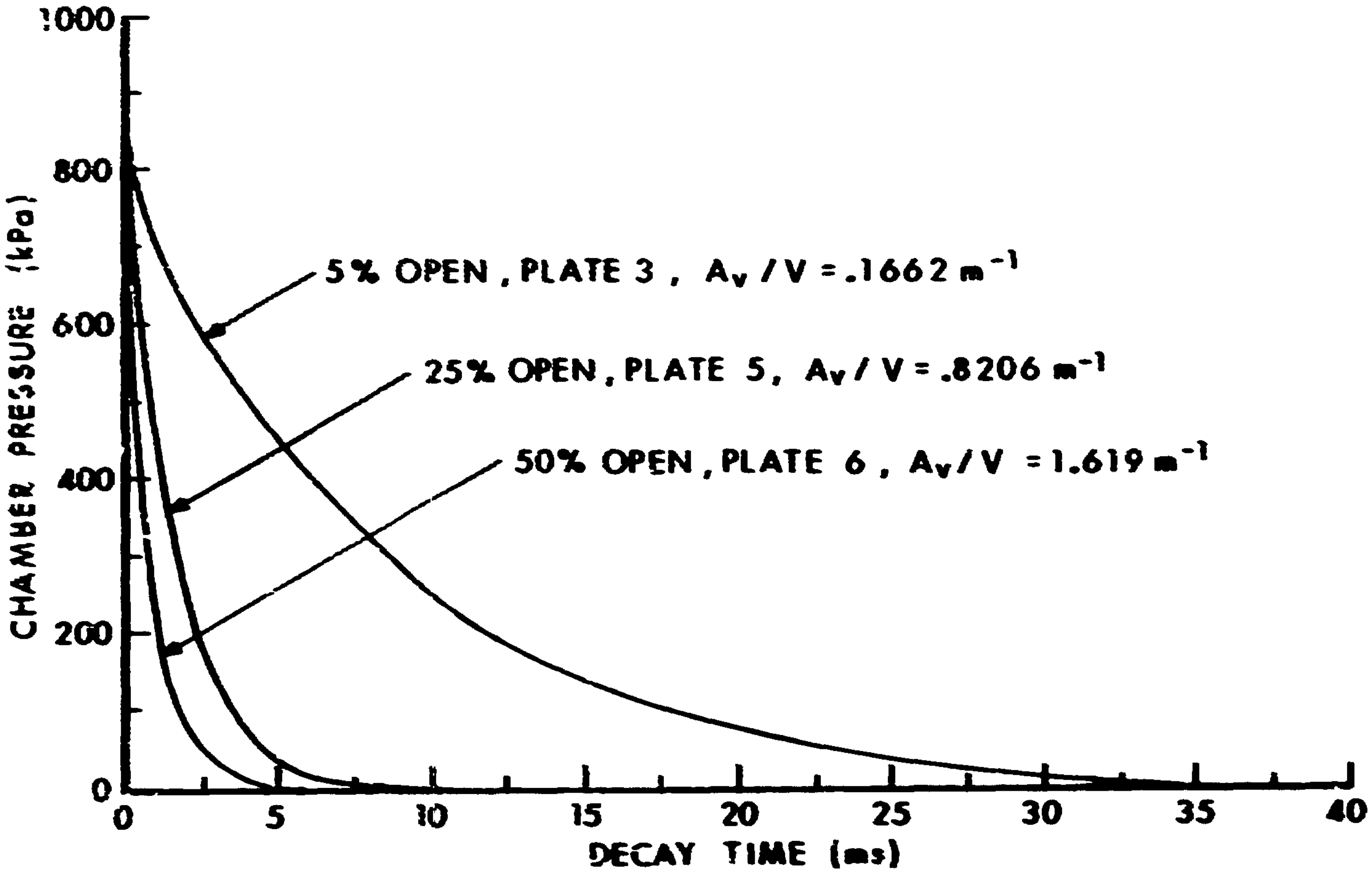

Figure 4. Chamber Pressure Decay versus Percent of Plate Vented, 827 kPa Initial Chamber Pressure

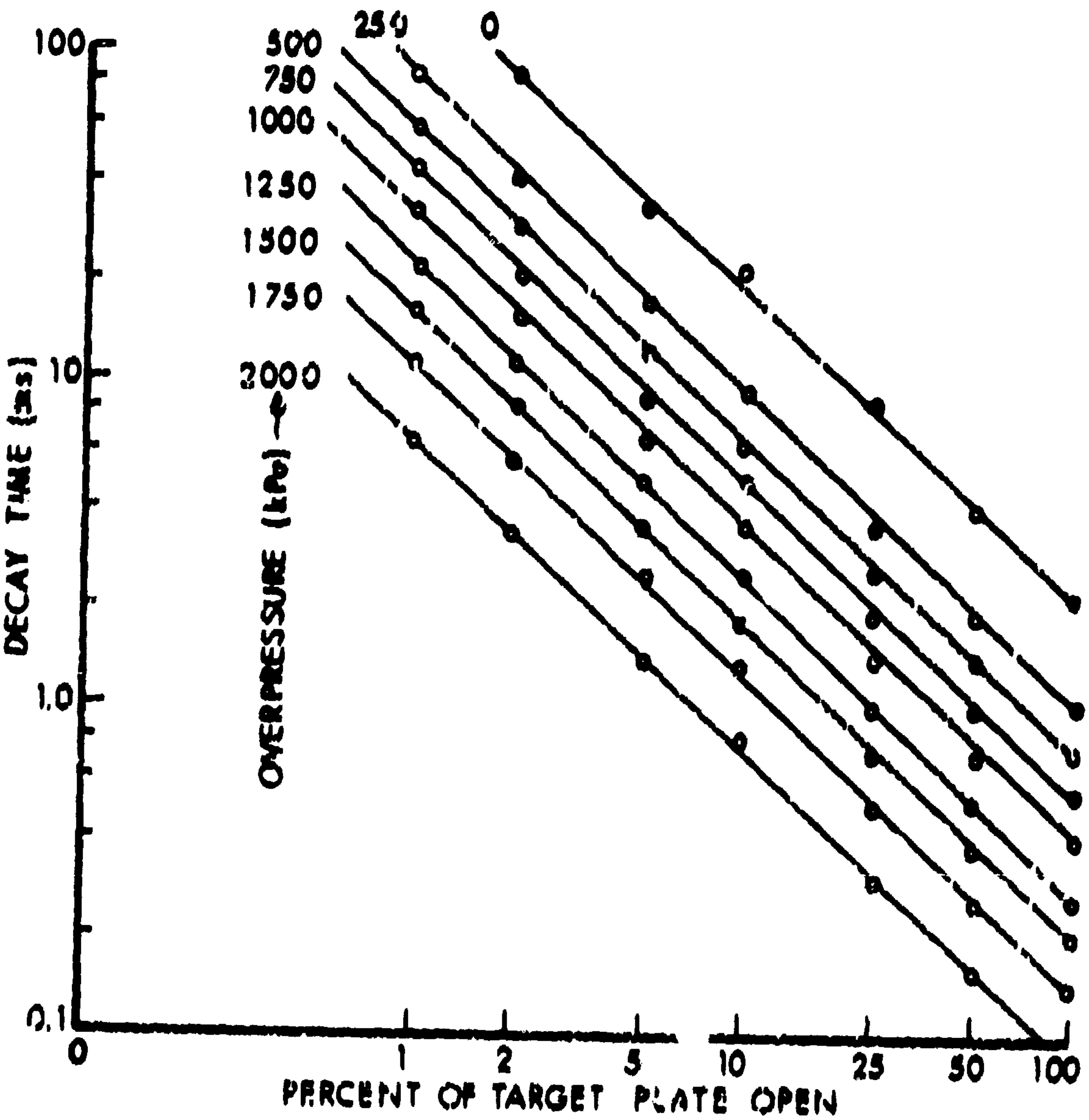

Figure 5. Pressure Decay versus Percent Open - 2413 kPa

versus time for Targets 7, 8, and 9 are presented in Figure 6. By matching the chamber pressure decay rate with the data plotted in Figure 5, it was determined that Target Plates 7, 8, and 9 had effective vent areas 18.0, 14.4, and 4.1 percent relative to single plate vent area percent. The ratios A_v/V for Target Plates 7, 8, and 9 are 0.5910, 0.4726, and 0.1346 m^{-1}.

C. Slotted Plate Venting.

The slotted plate is noted as Target Plate 10 in Figure 2. The chamber pressure decay versus time is plotted in Figure 7. Comparing the chamber pressure decay plotted in Figure 7 with the family of curves in Figure 5 an average effective vent area was determined to be 27 percent. The designed percent of area vented was 26 percent. This would imply that the slotted plate was as efficient in blast attenuation as a plate of the same vent area consisting of holes. The ratio of vent area A_v to volume V is 0.8861 m^{-1}.

D. Nested I-Beam Venting.

The nested I-beam, Target 11, was of interest because it was one of the wall configurations considered for a full scale test of the suppressive structure concept. Tests were conducted at the BRL[3] on a 1/4 scale model of a proposed structure utilizing walls of nested I-beams. Target 11 was a 1/16 scale of the proposed full size configuration. The chamber pressure decay versus time for a static pressure of 2413 kPa (350 psi) is presented in Figure 8. When the pressure versus time from Figure 8 is compared with the vent area plot for single plates in Figure 5 an effective vent area of 8.1 percent was estimated. The 8.1 percent of the plate area vented would give a A_v/V ratio of 0.2658m^{-1}.

IV. CORRELATION WITH OTHER WORK

There are many reports relating to internal explosions, but results applying more directly to the problem addressed in this report are noted in References 4 and 5. In both Reference 4 and 5 equations were established to describe the decay of internal pressure for various venting conditions using the chamber volume as one of the parameters.

3. *R. Schumacher, C. Kingery, W. Ewing, "Airblast and Structural Response Testing of a 1/4 Scale Category I Suppressive Shield," BRL Memo. Report 2623, May 1976.* (AD #B011616L)
4. *W.A. Keenan and J.A. Tancreto, "Blast Environment from Fully and Partially Vented Explosions in Cubicles". Civil Engineering Laboratory Tech Report 51-027, Feb. 1974.*
5. *C.F. Kinney and R.C. Sewell, "Venting of Explosion," NWC TEch. Memo. Report 2488, Naval Weapons Center, CA, July 1974.*

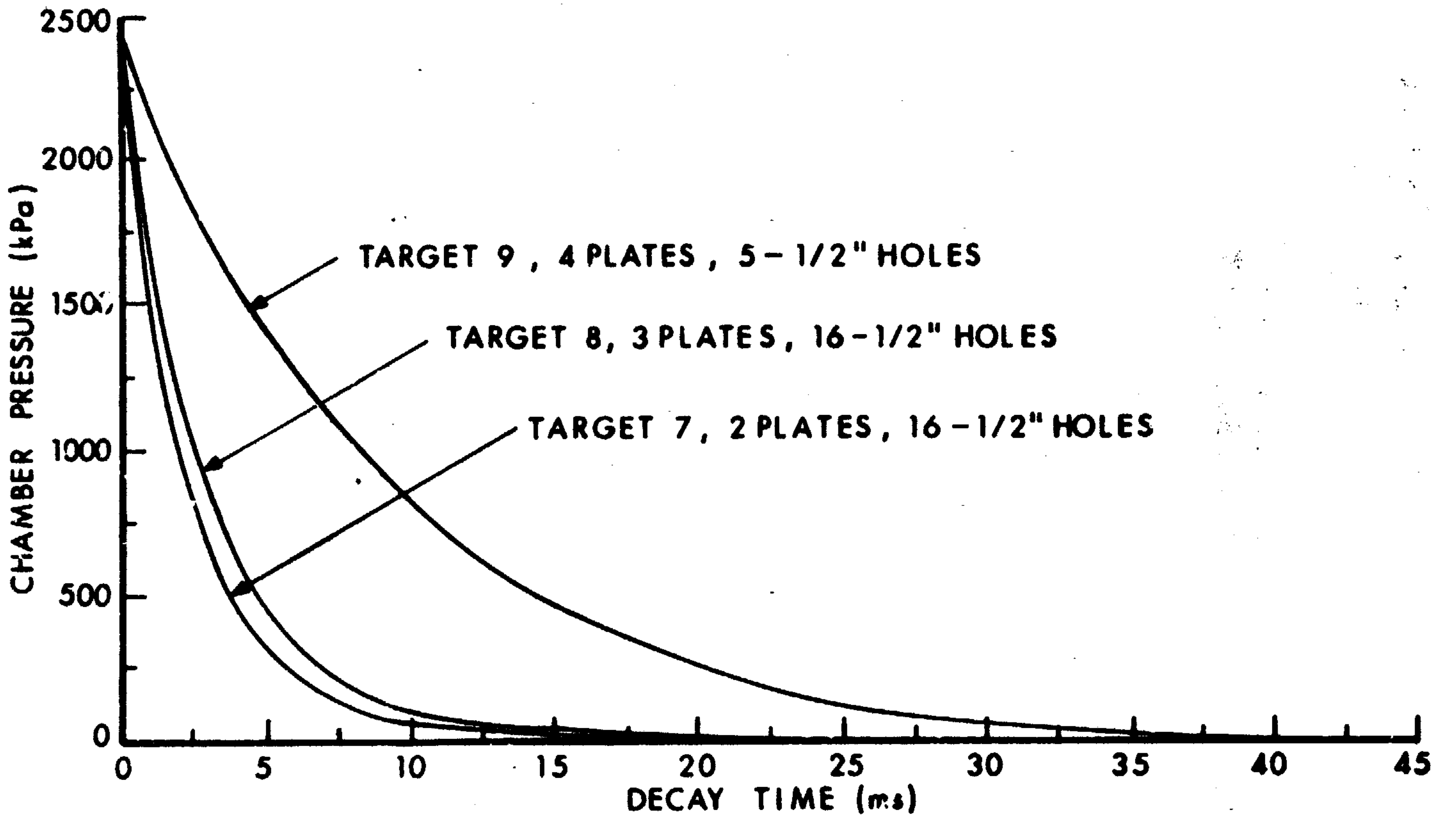

Figure 6. Chamber Pressure Decay versus Time for Multiple Plate Targets

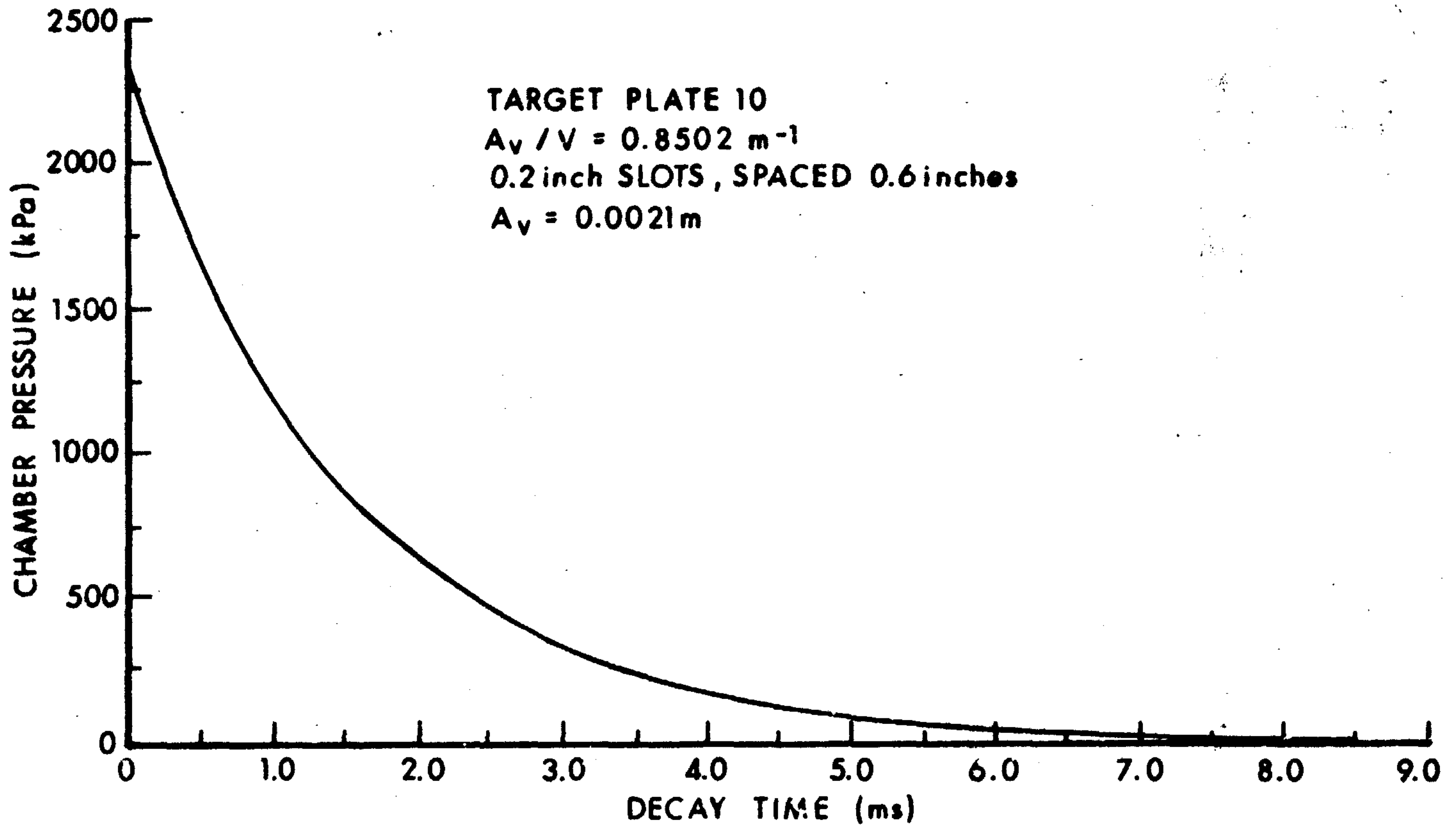

Figure 7. Chamber Pressure Decay versus Time - Slotted Plate

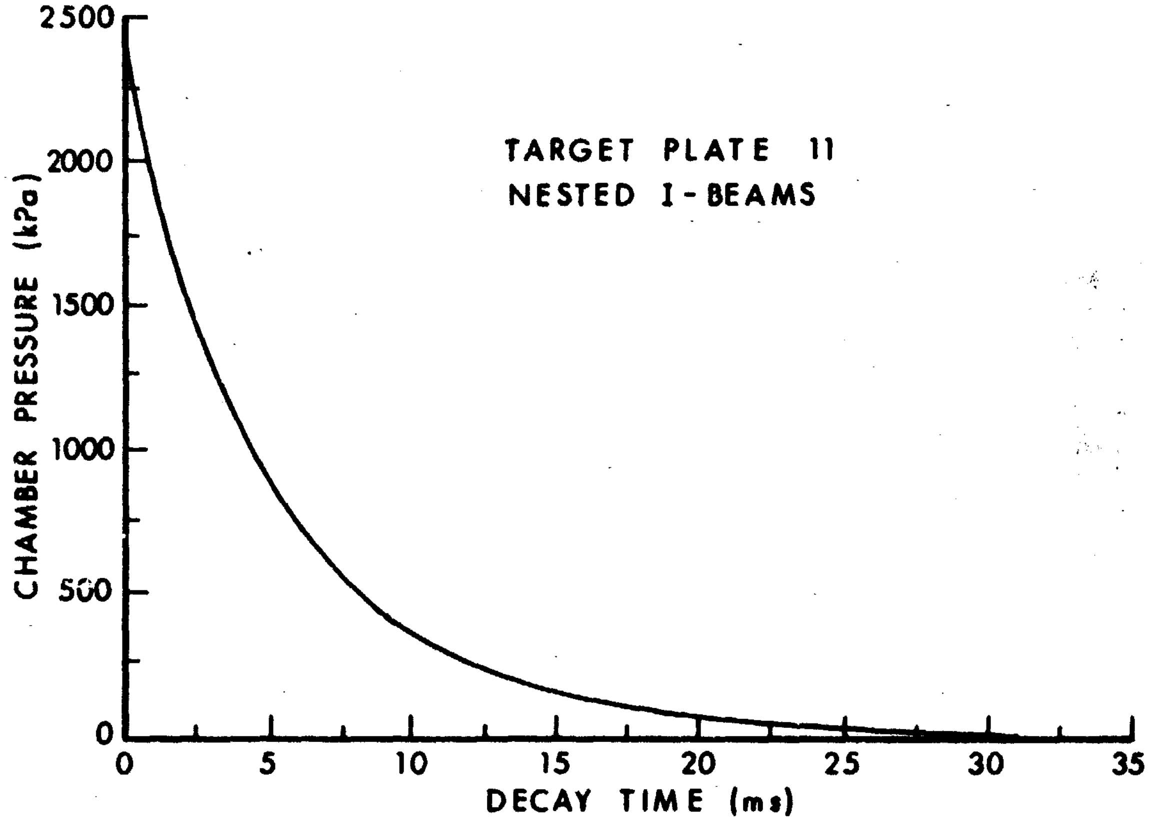

Figure 8. Chamber Pressure Decay versus Time, Nested I-Beams

A. Chamber Pressure Decay-Function of Vent Area and Volume.

The volume of the compression chamber remained constant ($v = .00247\ m^3$ or $.08727\ ft^3$) through the series of tests. Since the chamber pressure decay appeared to be exponential, the data were used to establish an equation in the form of

$$P_t = P_m\, e^{-c\left(\frac{A_v}{V}\right) t} \; ; \qquad (1)$$

where P_t = overpressure in the chamber at ime t,

P_m = chamber pressure at time, t=0,

C = empirically determined constant, 0.840, $^{m}/_{ms}$

A_v = area vented, m^2

V = chamber volume, m^3, and

t = time, milliseconds, ms.

NOTE: Overpressure may be kPa or psi.

Using Equation 1, chamber pressure decays versus time were calculated for the target plates described in Table I that were exposed to a 2413 kPa (350 psi) chamber pressure. These calculations are presented in Figure 9, along with experimental data points. Using Equation 1 to calculate the chamber pressure decay versus time implies an infinite duration because of the asymptotic approach to zero overpressure. The impulse calculated using Equation 1 is approximately one percent greater than would be obtained from the recorded pressure decay versus time to zero overpressure.

One method for determining the time (tg) for the chamber pressure to reach atmospheric pressure is to refer to Figure 5 in which decay time is plotted as a function of percent of target plate vented. From Table I this can be converted to area vented, A_v, divided by chamber volume, V, in meters^{-1}. An equation describing the time (tg) for the gas pressure to decay to ambient conditions or zero overpressure is

$$tg = 6.4\left(A_v/V\right)^{-0.95} \; , \qquad (2)$$

where A_v/V is metres^{-1}, and tg is milliseconds.

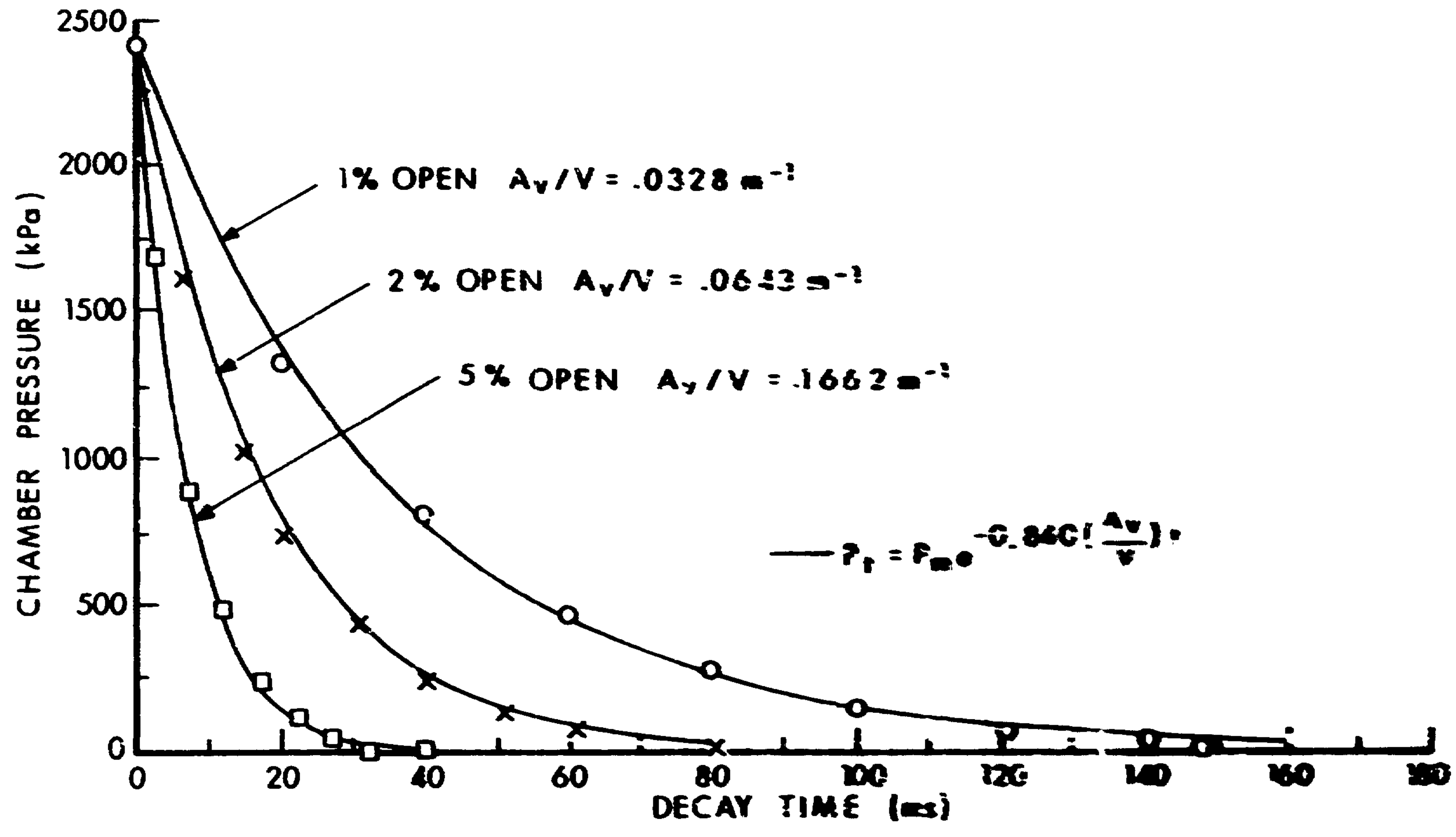

Figure 9. Chamber Pressure versus Decay Time, Equation and Data

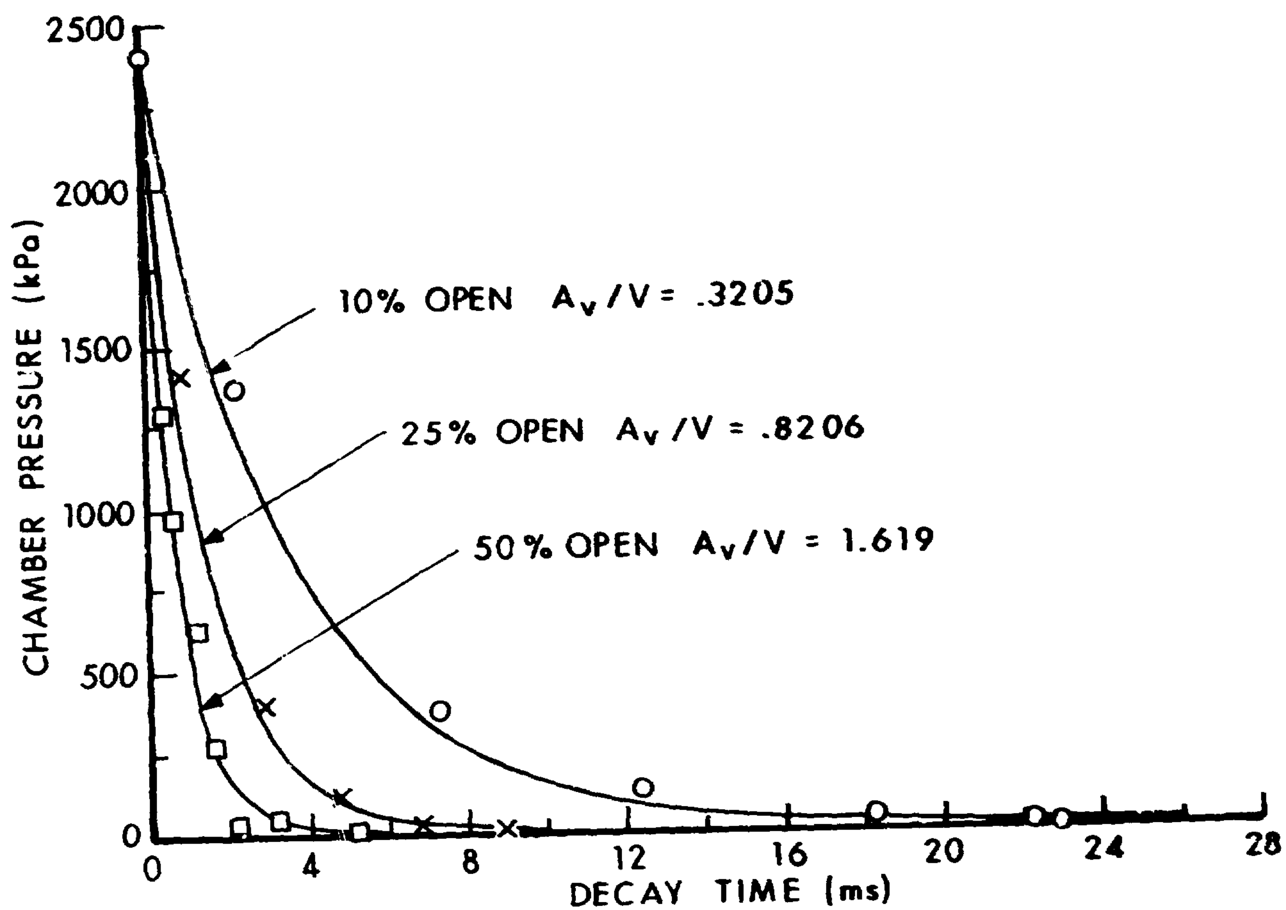

Figure 9. Chamber Pressure versus Decay Time, Equation and Data (Continued)

Using Equation 2 to determine the time (tg) required for the chamber pressure to decay to zero overpressure, and Equation 1 to describe the chamber pressure decay versus time out to time (tg), will give a good representation of the chamber pressure decay phenomenon. Impulse calculated using this method will be less than one percent smaller than impulse calculated using Equation 1 alone. Equations 1 and 2 were developed from results obtained from experiments using a chamber pressure of 2413 kPa (350 psi).

B. Chamber Pressure Decay Ratios.

A second way to correlate the results is to plot the chamber pressure decay as a ratio of overpressure (P_t) at time (t) divided by the maximum chamber pressure (Pm) as a function of a scaled delay time of $(A_v/V)t$. This plot is presented in Figure 10. A least squares fit to the data gave the following equation:

$$\log (Pt/Pm) = -.365\,(A_v/V)t, \qquad (3)$$

where A_v/V is metres^{-1} and t is in milliseconds.

Using the chamber pressure decay versus time, an effective vent area in metres^2 can be obtained for multiple plates as well as other target configurations by rewriting Equation 3 as follows:

$$A_v = \log \frac{P_t}{P_m} \times \frac{Vt}{-.365}\ . \qquad (3a)$$

Equation 3 was also found valid for the tests conducted with a maximum chamber pressure of 827 kPa (120 psi). This equation has the same limitation as Equation 1 in that it will not give a zero overpressure or duration of the gas pressure but as shown in Figure 10 it is valid at overpressures as small as 1 percent of the maximum chamber pressure (Pm).

The scaled decay for chamber pressure ratio was found experimentally to follow a negative slope of .365 metres per milliseconds. A comparison is made in Figure 11 between the chamber pressure decay versus time using the venting equation developed in Reference 5 from theoretical considerations and Equation 3 derived from experimental data.

The equation from Reference 5 is:

$$\log P_t = \log P_m - 0.315\left(A_v/V\right)t, \qquad (4)$$

where P_t and P_m are absolute pressures in atmospheres, A_v/V is the vent area to chamber volume in metres^{-1} and t is in milliseconds. The

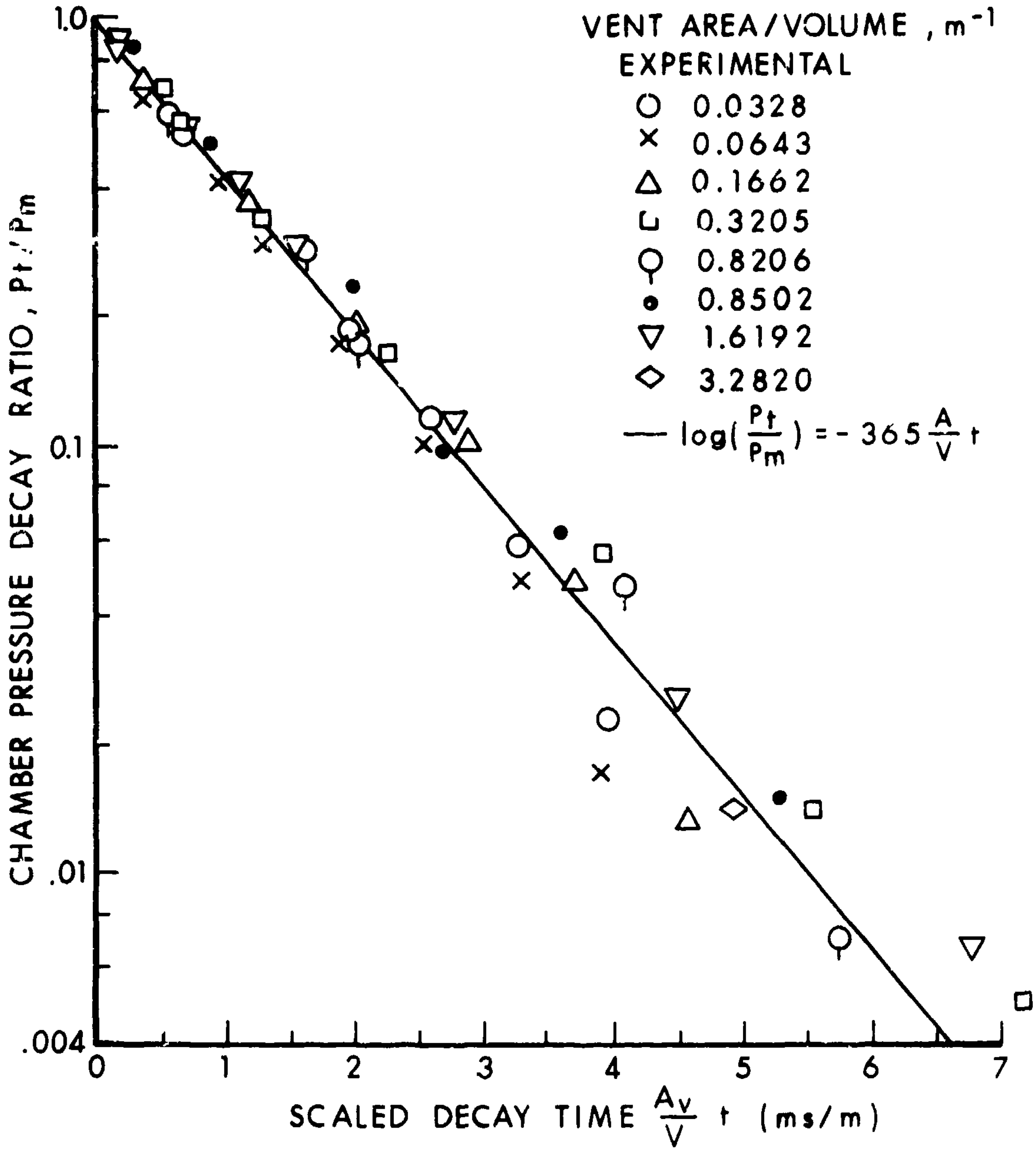

Figure 10. Chamber Pressure Decay Ratio as a Function of Scaled Decay Time

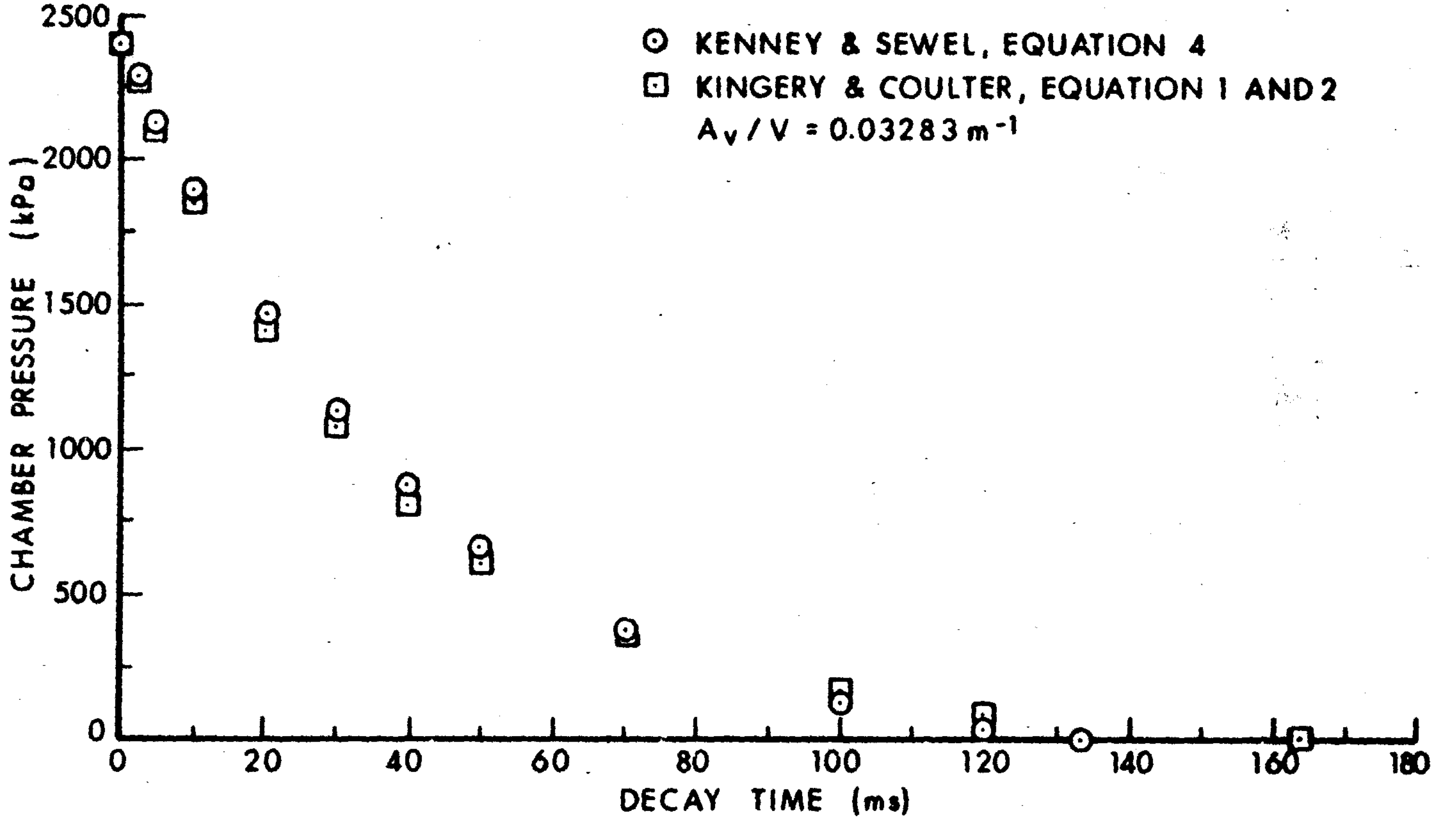

Figure 11. Comparison of Theory and Experiment

experimental decay data for a chamber filled with helium gas follows the proposed pressure decay curve of a chamber filled with hot explosive gases well enough to allow accurate predictions to be made for full-size suppressive structure panels.

C. Scaled Blow-Down Time.

Blow-Down time is a term used in Reference 6 to describe the time required for the chamber overpressure to decay to atmospheric pressure. An equation was developed which depended on maximum chamber pressure, vent area, and chamber volume. The equation is as follows:

$$\frac{tg}{P_m^{1/6} V^{1/3}} = \frac{(A_V)^{3/2}}{V} \quad ; \tag{5}$$

where P_m = chamber pressure, psi,

V = chamber volume, ft^3,

A_V = vent area, ft^2, and

tg = blow-down time, ms.

Figure 12 is a plot of $tg/\left(P_m^{1/6} V^{1/3}\right)$ versus $A_V^{3/2}/V$. Also presented in Figure 12 are the blow-down times obtained from this series of tests. The data points lie above the computed curve but are within the scatter of experimental results obtained from vented structures and high explosives.

In Reference 4, Keenan and Tamareto developed an equation to describe the duration of the gas overpressure in vented structures. The results were based on the firing of high explosive in chambers with known vent areas and volumes. The equation is:

$$tg/w^{1/3} = 2.26\ (A_V w^{1/3}/V)^{-0.86}. \tag{6}$$

If we set charge weight w equal to 1, then

$$tg = 2.26\ (A_V/V)^{-0.86}, \tag{7}$$

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6. *W.E. Baker and P.S. Westine, "Methods of Predicting Blast Loads Inside and Blast Fields Outside Suppressive Structures," Edgewood Arsenal Contractor Report EM-CR-76026, Nov. 1975.*

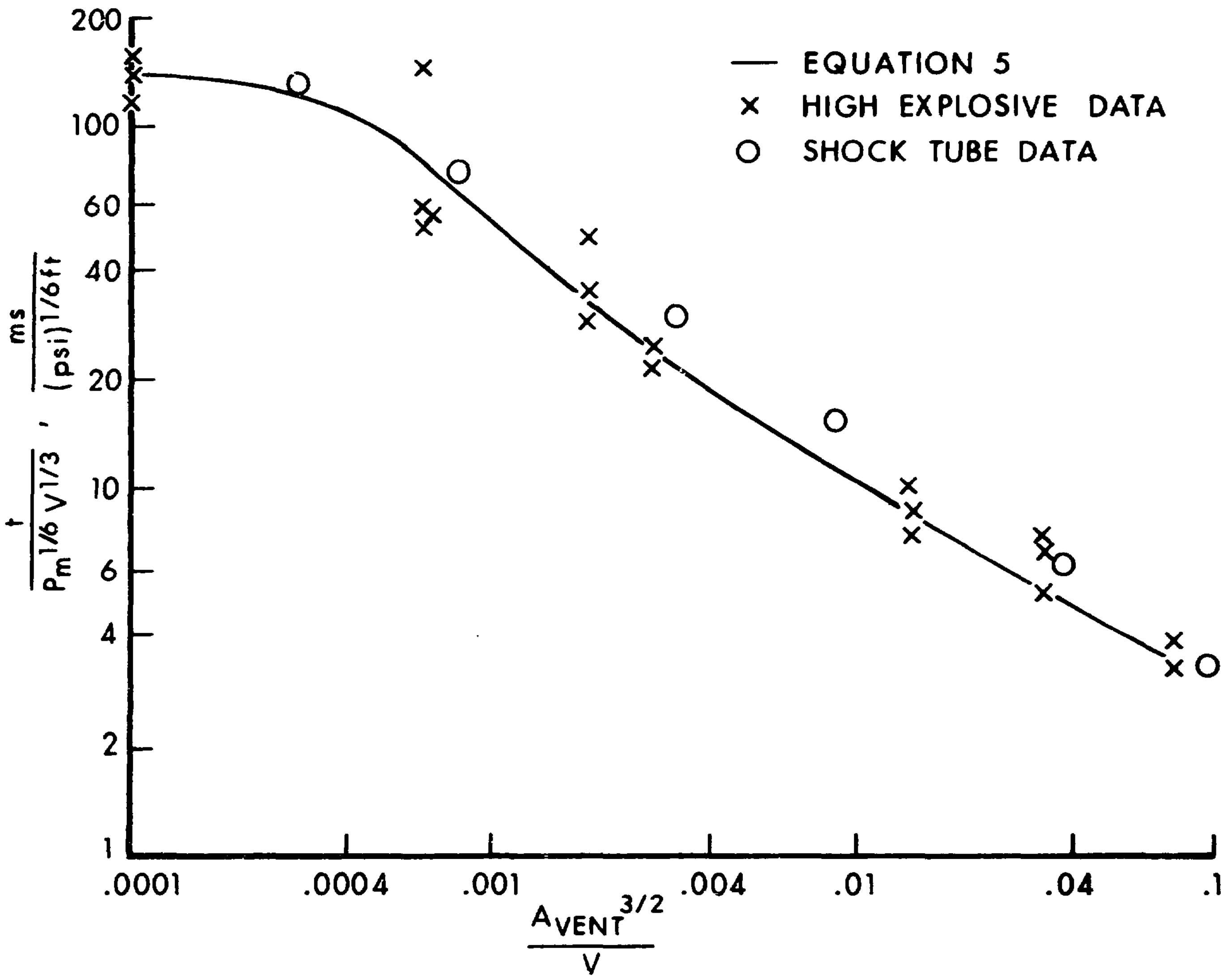

Figure 12. Scaled Blow-Down Time for Vented Structure

where tg = blow-down time, ms,

A_v = vent area, ft^2, and

V = volume, ft^3.

Note that this equation is very similar to Equation 2 with exception of the negative slope. Blow-down times calculated from Equation 7 are lower at the smaller vent areas than were obtained from Equation 2.

D. Multiple Plate Venting Predictions.

The chamber pressure decays for single plate targets with various vent areas have been measured and correlated with other investigations. Multiple plates targets have also been exposed and effective vent areas have been determined relative to single plate targets. One method, suggested in Reference 5 for predicting the effective vent area, A_v, for a multiwalled structure was to assume that

$$\frac{1}{\alpha_{eff}} = \frac{1}{\alpha_1} + \frac{1}{\alpha_2} + \cdots + \frac{1}{\alpha_n} \tag{8}$$

where n = number of elements in a suppressive structure panel,

$\alpha_i = \frac{\text{Vented Area}}{\text{Plate Area}}$, for each target element, and

$A_v = \alpha_{eff}$ x Plate Area (.00811m^2 or .08727 ft^2).

This equation is used to calculate the effective vent area for Target Plates 7,8,9 and 11 and the results are listed in Table III. It can be seen in Table III that the α_{eff} calculated from Equation 8 imply that the multiple plates are more efficient in containing the chamber pressure than the measured values would indicate. If Equation 8 is modified as follows:

$$\frac{1}{\alpha_{eff}} = \frac{1}{\alpha_1} + \frac{.5}{\alpha_2} + \frac{.25}{\alpha_3} + \frac{.125}{\alpha_4}, \tag{9}$$

then the predicted values from Equation 9 show a much better correlation with the measured values of α_{eff} than those predicted from Equation 8, as shown in Table III.

E. Multiple Plate Spacing.

One experiment was conducted to determine the effect of spacing between plates on the effective vent area. One test was conducted with two 1/4 inch thick plates having 16 - 1/2 inch holes and a 1/4 inch separation. This is presented as Target Plate 7 in Figure 6. A second test was conducted with the same plates but with a 1/2 inch separation. The chamber pressure decay versus time recorded from the two tests are presented in Figure 13. The data points fall well

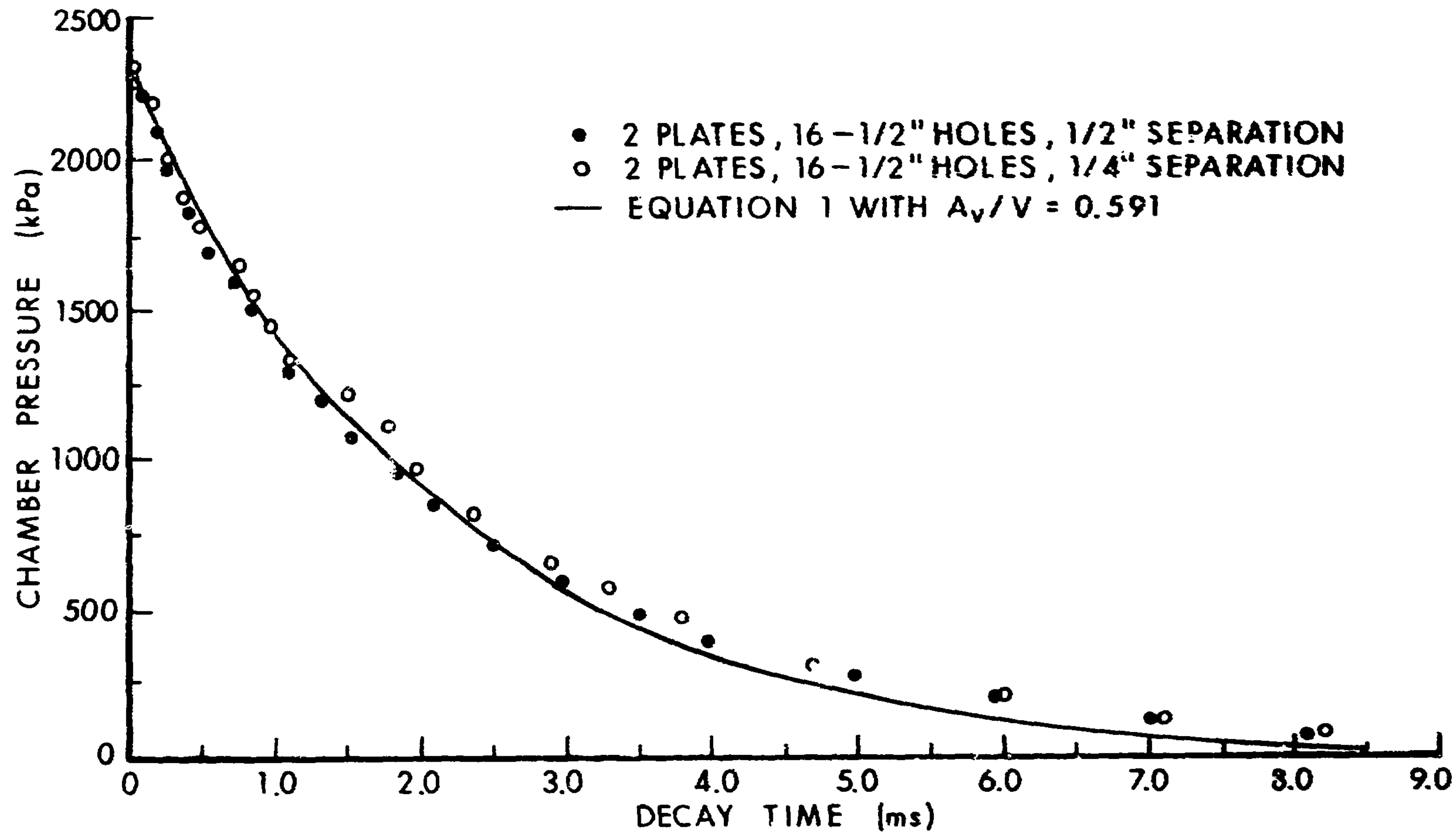

Figure 15. Effect of Target Plate Spacing

TABLE III. Comparison of Measured and Predicted Effective Vent Areas.

Target Plate	Measured	α_{eff} Predicted	Predicted	Target Plate Description
		Eq. 8	Eq. 9	
7	0.180	0.125	0.166	2 Plates 16-1/2" holes α = .25 each
8	0.144	0.083	0.143	3 Plates 16-1/2" holes α = .25 each
9	0.041	0.019	0.042	4 Plates 5-1/2" holes α = .078 each
11	0.081	0.037	0.083	Nested I-beams

within the scatter that might be expected from two similar tests. It can be concluded that there was no difference in the chamber pressure decay versus time when the spacing was increased from 1/4 inch to 1/2 inch.

F. Comparison With Field Tests.

The true worth, of prediction techniques developed from computer programs or laboratory experiments, is determined when they can be compared with reliable field test results. The decay of quasi-static pressure versus time was recorded on a series of field tests for a number of charge weights and vent areas, and are reported in Reference 3. Based on the average vent area (A_v) listed in Table X of Reference 3 for Shots 191, 194, and 196 which were 2.685, 1.171, and .3633m^2, the decay of chamber pressure versus time was calculated for the structure volume of 28.15 m^3 using Equation 1. The calculated points from Equation 1 are plotted in Figures 14, 15, and 16, to show the comparison of field test records and the calculated values from Equation 1.

A similar comparison is made in Figures 17, 18, and 19. Here the calculations from Equation 1 are compared with the records of overpressure versus time obtained from a series of field tests described in Reference 7.

7. *Charles Kingery, R. Schumacher, W. Ewing, "Internal Pressure from Explosions in Suppressive Structures," BRL Memo. Report (in publication).*

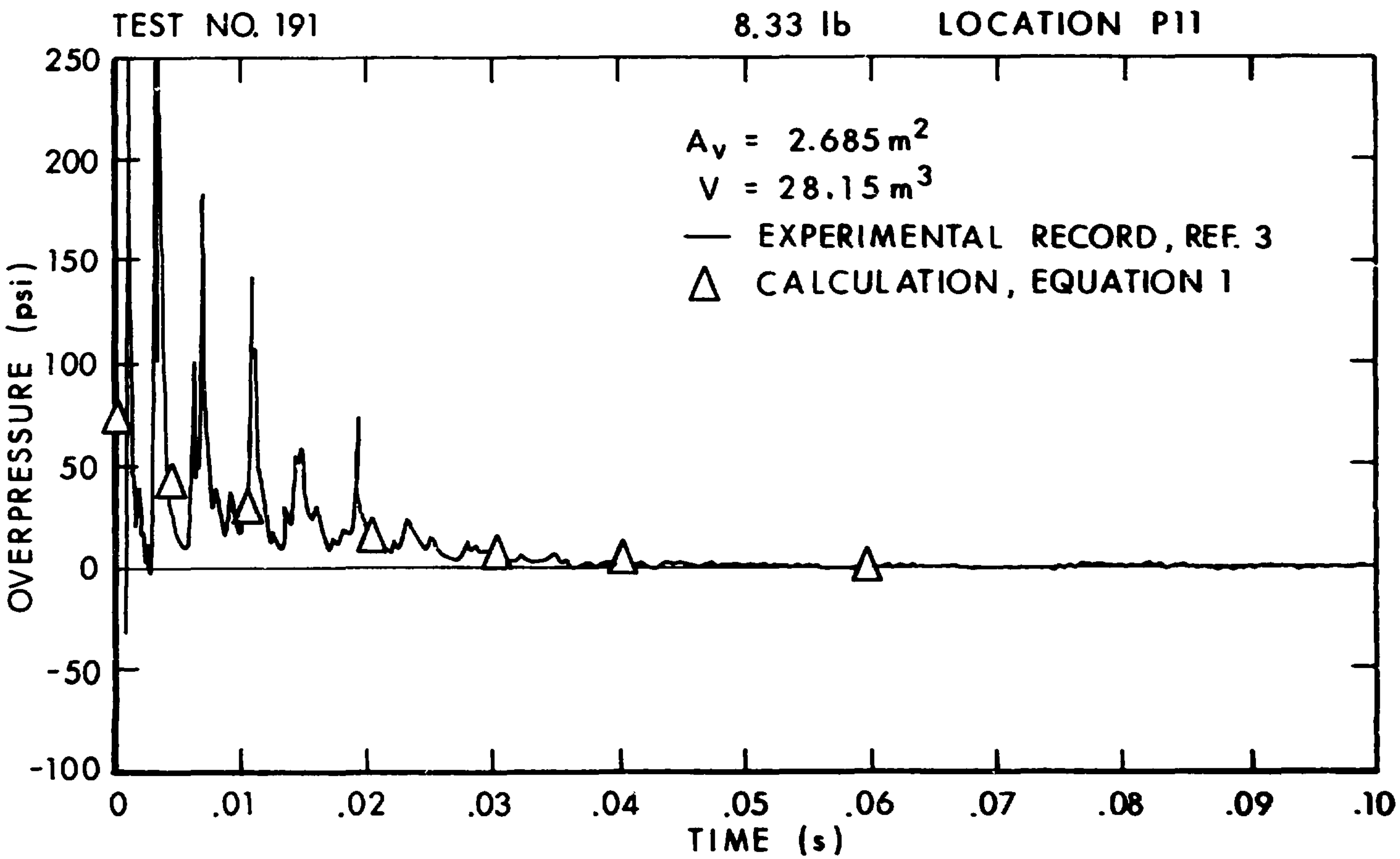

Figure 14. Internal Pressure Decay versus Time, Experimental and Calculation for A_V/V of 0.0954m^{-1}

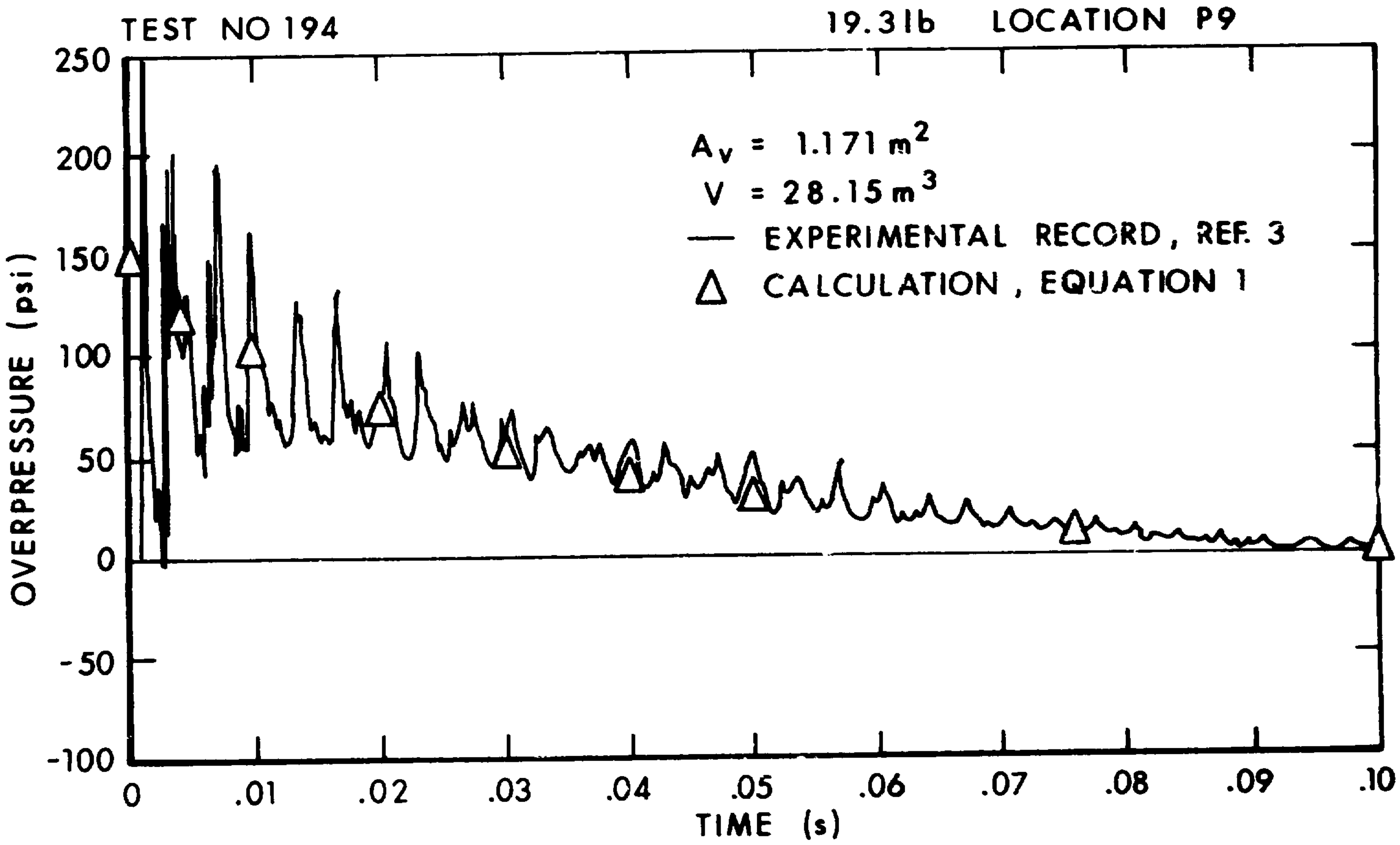

Figure 15. Internal Pressure Decay versus Time, Experimental and Calculation for A_v/V of 0.0416m^{-1}

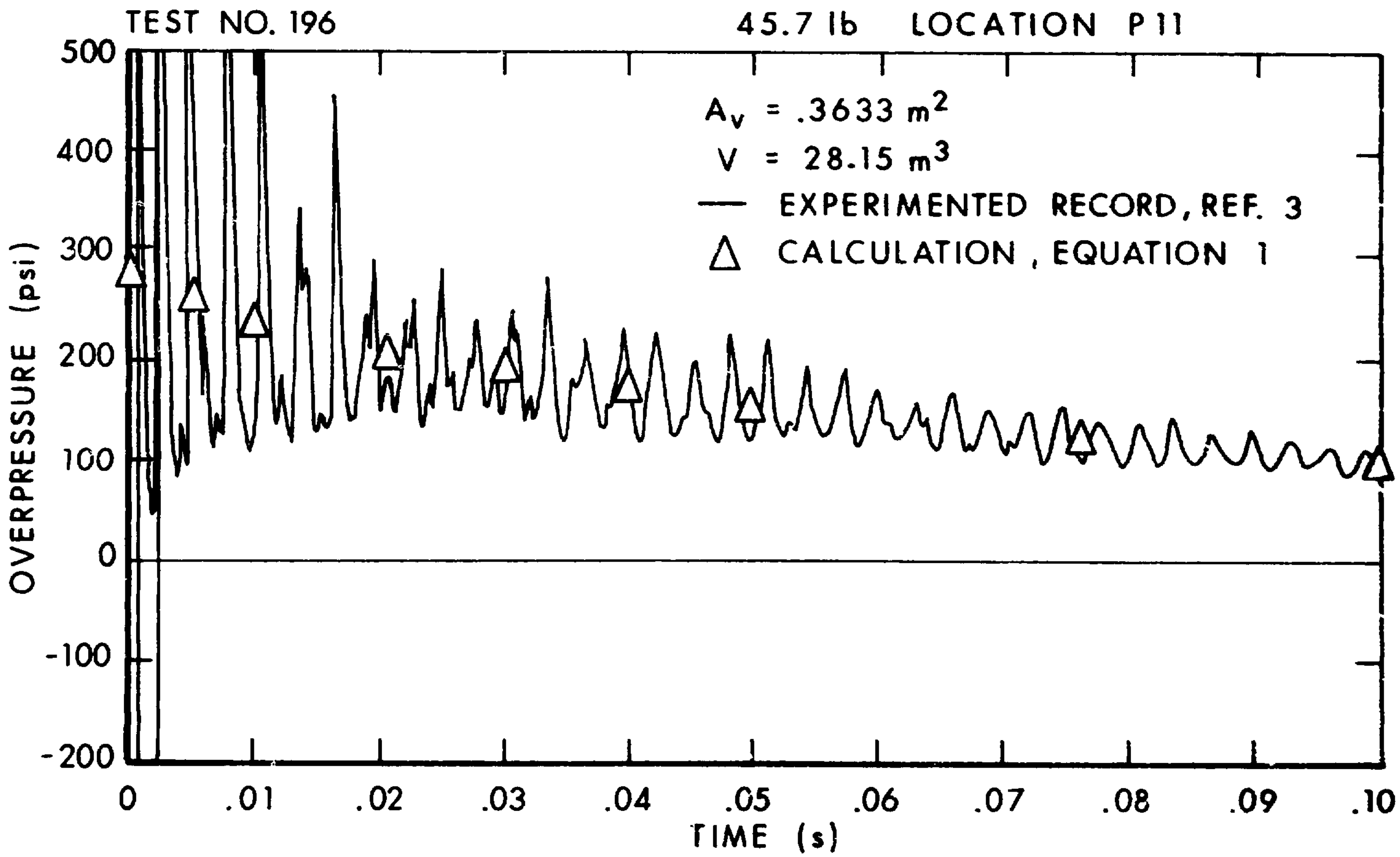

Figure 16. Internal Pressure Decay versus Time, Experimental and Calculation for A_v/V of $0.0129 m^{-1}$

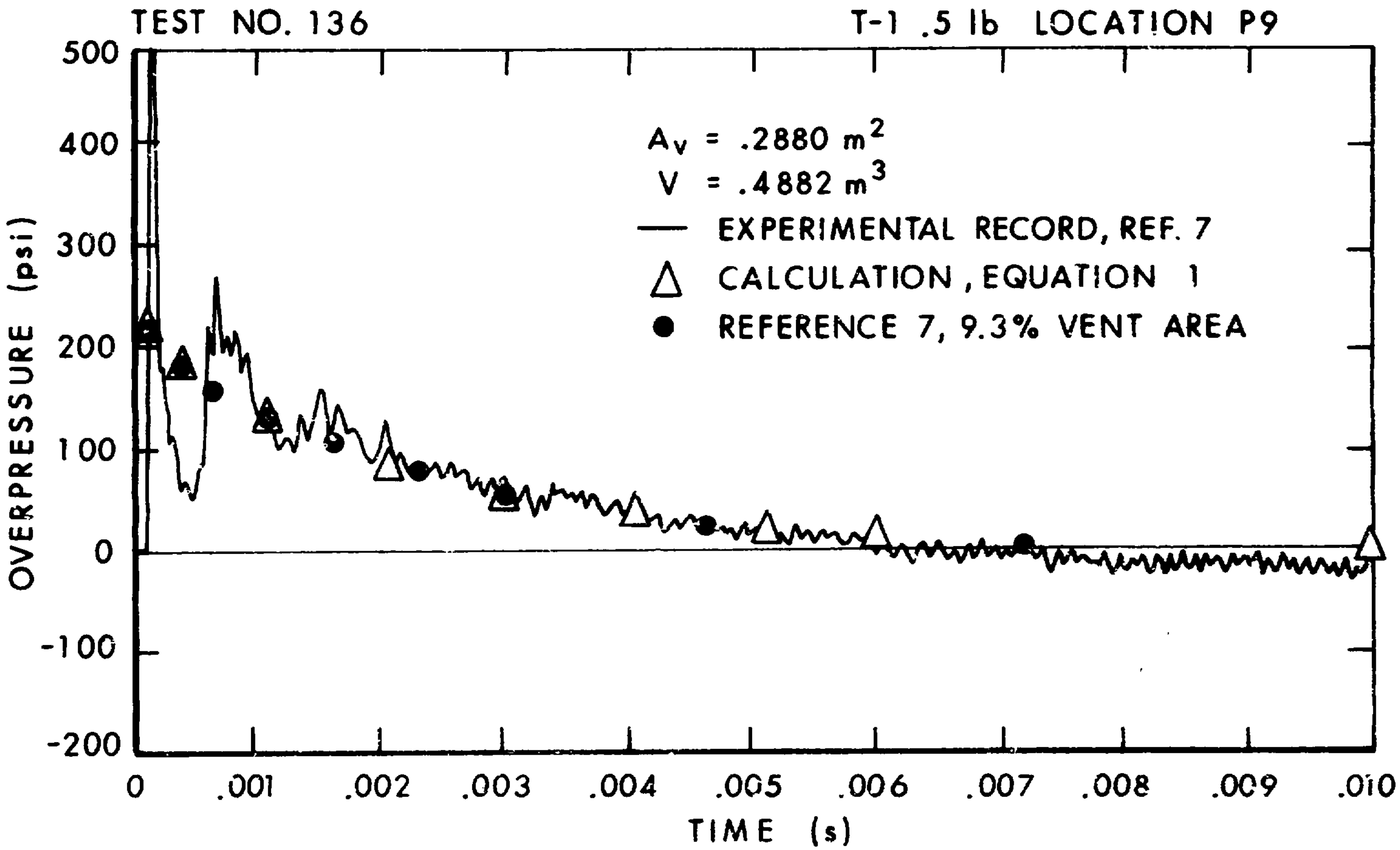

Figure 17. Internal Pressure Decay versus Time, Experimental and Calculation for A_v/V of $0.5899 m^{-1}$

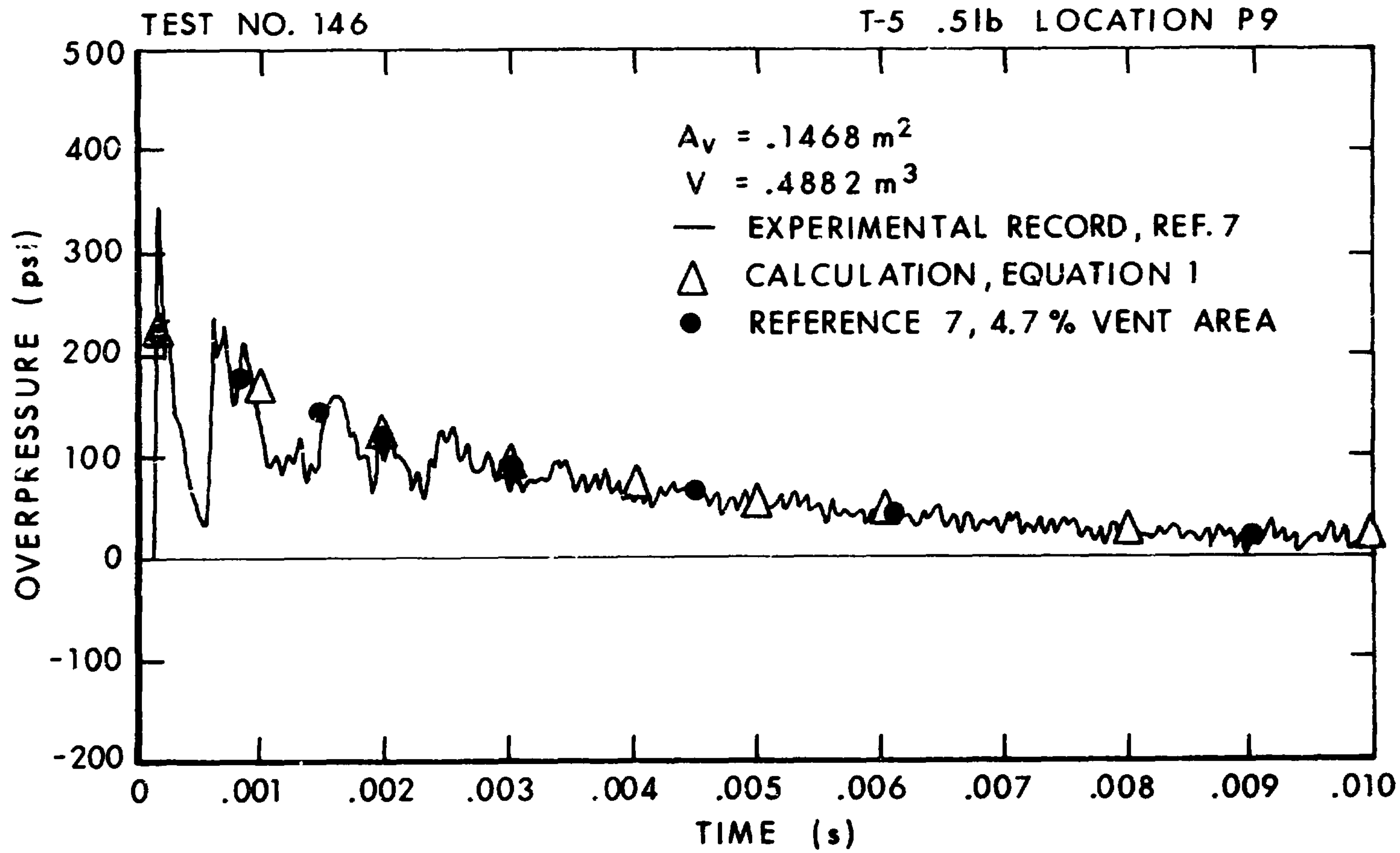

Figure 18. internal Pressure Decay versus Time, Experimental and Calculation for A_v/V of $0.3007m^{-1}$

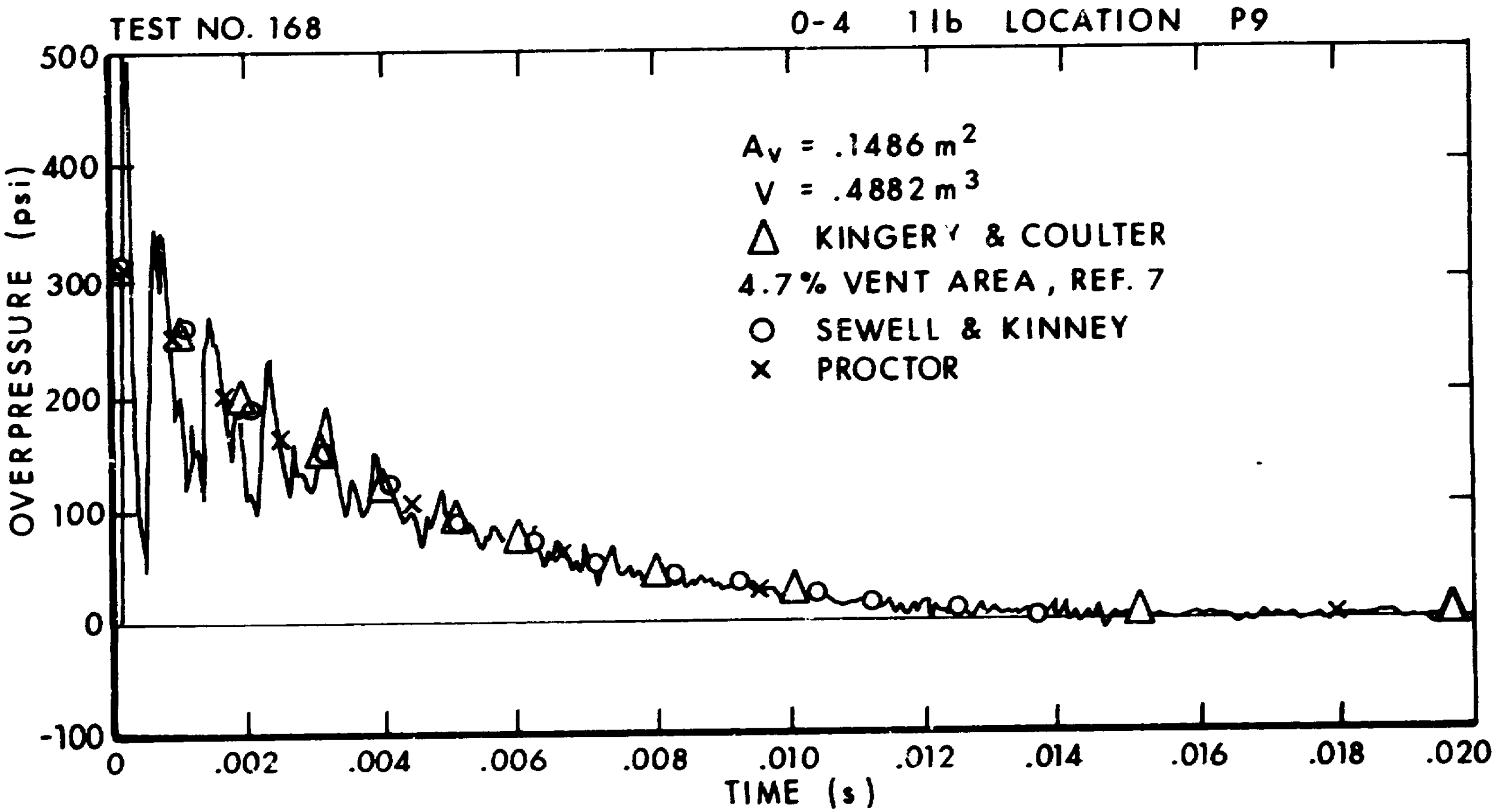

Figure 19. Internal Pressure Decay versus Time, Experimental and Calculation for A_v/V of $0.3044 m^{-1}$

In Figure 19, along with calculations from Equation 1, there are also data points calculated from Equation 4 (Sewell and Kinney) and from Proctor's code described in Reference 8. The correlation between the three methods for computing the chamber pressure versus time is much better than could be expected since in the field tests the chambers were filled with hot gases and detonation products while the shock tube compression chamber was filled with helium gas. The chamber volume of the 1/4 scale structure described in Reference 3 is over 11,000 times the volume of the shock tube compression chamber.

V. CONCLUSIONS

A series of experiments were conducted in which the chamber pressure decay versus time through vented plates was recorded within a chamber pressurized with helium gas. The effect of known vent areas on the pressure decay rate was documented.

A comparison of the results with other experimental and analytical work was made and the conclusions are that a good simulation of hot explosive gases venting through suppressive structure panels was obtained.

Effective vent areas were established for selected multiple plates and model I-beams. An equation was developed for predicting the effective vent area for multiple walls of complex suppressive structures.

The results obtained from this experimental program have shown that a relatively simple and economical test program can provide answers to the complex questions of gas flow through proposed suppressive structure walls and panels.

It is believed by the authors that the equations developed in this report can be used to describe the venting of gases from pressurized containers as well as accidental explosions in containment structures.

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8. *Proctor, J.F., "Internal Blast Damage Mechanisms Computer Program," 61 JTCG/ME-73-3, 10 April 1973.*

REFERENCES

1. Charles Kingery and George Coulter, "Shock Wave Attenuation by Single Perforated Plates," Ballistic Research Laboratory Memorandum Report No. 2664, August 1976. (AD #B013764L)

2. C. Kingery, R. Pearson, and G. Coulter, "Shock Wave Attenuation by Perforated Plates With Various Hole Sizes," BRL Memo Report No. 2757, June 1977. (AD #A041854)

3. R. Schumacher, C. Kingery, W. Ewing, "Airblast and Structural Response Testing of a 1/4 Scale Category I Suppressive Shield," BRL Memo. Report 2623, May 1976. (AD #B011616L)

4. W.A. Keenan and J.A. Tamareto, "Blast Environment from Fully and Partially Vented Explosions in Cubicles". Civil Engineering Laboratory Tech Report 51-027, Feb. 1974.

5. C.F. Kinney and R.C. Sewell, "Venting of Explosion", NWC Tech. Memo. Report 2488, Naval Weapons Center, CA, July 1974.

6. W.E. Baker and P.S. Westine, "Methods of Predicting Blast Loads Inside and Blast Fields Outside Suppressive Structures," Edgewood Arsenal Contractor Report EM-CR-76026, Nov. 1975.

7. Charles Kingery, R.Schumacher, W. Ewing, "Internal Pressure from Explosions in Suppressive Structures," BRL Memo. Report (in publication).

8. Proctor, J.F., "Internal Blast Damage Mechanisms Computer Program," 61 JTCG/ME-73-3, 10 April 1973.

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